

The effect of vehicle weight on the sound produced by transverse rumble strips

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ABSTRACT

Transverse rumble strips (TRS) are commonly used as traffic calming measure in the vicinity of premises. So far research have been extensively concentrated on the effect of vehicle type and speed on the noise produced by TRS, and very little research focused on the effect of vehicle weight. Do these vehicles produce extremely higher sound level parallel to their heavier weight? This is important as in reality, traffic flow consist of light, medium and heavy vehicles, which are also important sources of noise. This study investigated the effect of vehicle weight, such as gross vehicle weight (GVW) when transited on TRS, particularly with emphasis on impulsivity content. The objectives of this research were to: (1) determine the effect of GVW on noise generation when a vehicle transits on TRS and (2) assess the effect of GVW on the impulsivity of noise. Data from vehicles with weight between 800 kg - 8000 kg were collected based on previous research where these vehicles were tested on speed values of 30km/h and 50km/h. It was found that when the vehicles transited on TRS, the generated noise was strongly related with the vehicle weights ($R^2=0.71$) higher than those normal road surface ($R^2=0.49$). However, the changes of noise were not well represented by direct relation. It was found that TRS can increase and decrease the sound pressure level, depending on GVW, but on average, TRS can increase the sound pressure level by 1 dBA. Despite that, TRS was found to have an impulsive characteristic within the tested speed range. This finding can facilitate the authority to evaluate the environmental noise produced by TRS.

Keywords: Traffic noise; rumble strips; impulsive noise; engine noise; tyre noise; road noise.

INTRODUCTION

Transverse rumble strips (TRS) is a set of transverse bars fabricated perpendicular to vehicle direction flow on the roadway. Worldwide, the authority uses TRS to alert drivers for the upcoming situation, for example, before they reach a critical point like a junction, roundabout, road hump, and pedestrians to reduce accident rate [1-5]. In Malaysia, an average of 3,500 people sustains severe damages and loss of lives daily due to head-on and side collisions [6-8]. Therefore, comprehensive actions that involve road safety awareness, decent road infrastructure provision and good vehicle ecosystems are given priority by the government. As a result, the usage of TRS can be considered as one of the requirements for providing a decent road infrastructure.

Two types of TRS materials are available, which are concrete or pavement that are milled or grooved, and thermoplastic fabricated on road surface. The latter is the common choice in ASEAN countries, including Malaysia, because it is easily installed, durable, have good reflectivity characteristic, and low cost. Various thermoplastic TRS profiles are installed near premises, such as shops, clinics, schools, and homes. Othman et al. [9] have classified them as Multi-Layer overlap (MLO), Middle layer overlap (MO), and Raise Rumbler (RR). The excessive noise produced by TRS installation is annoyance to the neighborhood, as stated by Othman et al. [9] and Datta et al. [10].



Figure 1. Types of thermoplastic rumble strips profiles.

Vehicle speed and type were the subject of interested investigation towards the generation of sound pressure level (SPL) when vehicle transit on TRS [11-15]. Most extensive reports on noise level changes due to TRS were from the milled or grooved TRS on road surface [11, 13, 16, 17], whereas very little were from the thermoplastic TRS [18, 14, 19, 20]. The reports had tested on the tactile and audible warning produced by different thermoplastic TRS configurations that were installed on a two-lane Thailand highway. Pickup vehicles with various test speed (50 km/h, 70 km/h, and 90 km/h) were used, with finding that it is likely to create higher roadside sound difference by about 1-2 dB(A) [18].

Another report found that a 980 kg compact car (Myvi) generated a significant increase in sound pressure level at the speed of 70 km/h than 30 km/h transited on various thickness and thermoplastic TRS profiles [14]. They related the increase with the tyre-TRS interaction for the higher sound increase at the speed of greater than 30 km/h, which was similar with the normal condition of tyre-road surface suggested by [30]. Furthermore, noise level changes on two types of thermoplastic TRSs with two different profiles of thermoplastic TRS with the same thickness of 3mm [19,20]. Three types of lightweight vehicle with Saga, Axia,

and Alza [19] and four types of commercial vehicles with Hilux, a multipurpose van, a one tonne lorry, and a 40-seater school bus [20] were tested with various speed.

From the literature, research had so far focused on the effect of vehicle types, such as compact car, sedan, pickup, and multipurpose van. However, very little research were carried out on the effect of vehicle weight on the noise produced by TRS. Do these vehicles produce extremely higher sound level parallel to their heavier weights? This is important as in reality, traffic flow consists of light, medium and heavy vehicles, which are important noise sources. Trucks particularly produce more noise due to their axle loads. If the axle load of a truck is reduced from nearly 2000 kg to 500 kg, a 15 dB(A) decrease in noise level can be obtained [21].

This study investigated the effect of vehicle weights, such as gross vehicle weight (GVW) when transited on TRS, particularly on impulsivity content. The objectives of this research were to: (1) determine the effect of vehicles GVW on noise level changes when a vehicle transited on TRS, and (2) assess the effect of GVW on the impulsivity of noise. Determination of these effects could enable the exploration of TRS impact on traffic noise condition so that it can facilitate the authority to manage environmental noise.

PREVIOUS RESEARCH RELATED TO THIS STUDY

Previous works by authors in [19,20] investigated the effect of three types of lightweight vehicle, such as Saga, Axia, and Alza [19] and commercial vehicles like Hilux, multipurpose van, 1- tonne lorry, and 40-seater school bus [20] (Figure 2) on noise level and impulsivity of noise when they hit the two types of TRS, i.e MO and MLO. The test speed of 30 km/h, 50 km/h, and 70 km/h were for the lightweight vehicles, while 30 km/h and 50 km/h were for commercial vehicles. The experiments were carried out by using the same stretches and layout (Figure 3) with the methodology explained in [19,20]. The thickness, width, spacing, length, and number of strips are shown in Table 1. Data obtained by Control pass-by (CPB) [22] at two points located oppositely (Figure 2) include L_{Aeq} , L_{AFmax} , L_{ASmax} , L_{AImax} , and L_{AIeqT} . L_{AFmax} was equivalent to A-weighted maximum fast response, L_{AImax} was maximum A-weighted impulse response, L_{AIeqT} was averaged A-weighted impulse sound pressure levels over the same time interval, and L_{ASmax} was A-weighted maximum slow response.

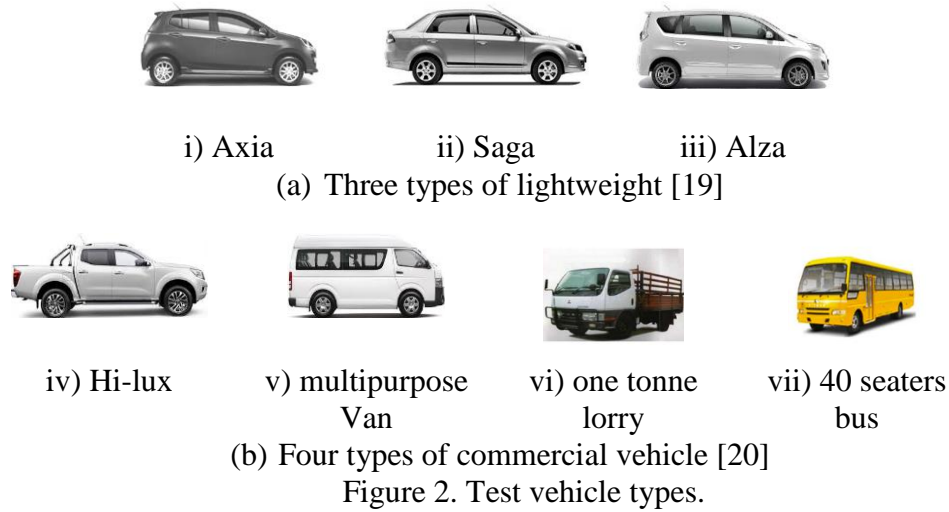
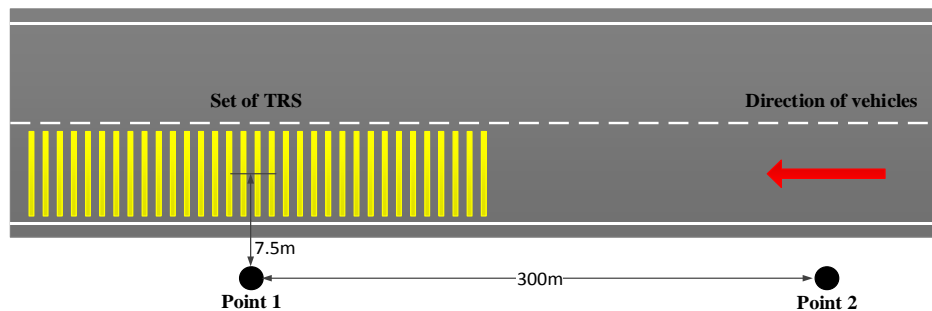
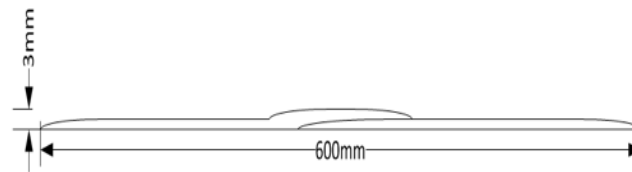


Table 1. Dimension and number of strips of MO and MLO [19,20].

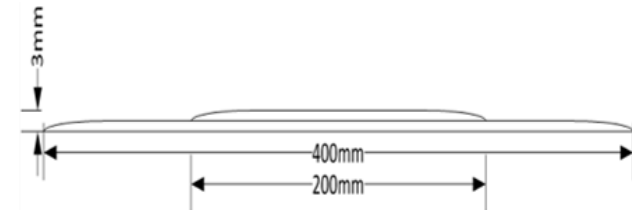
Type of TRS	Middle Overlapped (MO)	Multiple layer overlap (MLO)
Thickness	3 mm	3 mm
Width	600 mm	400 mm
Spacing	2350 mm	2450 mm
Length	3350 mm	2800 mm
Number	33	30

Measurement were carried out by using Point 1 was to capture these data when the vehicles transit on TRS, while Point 2 was without TRS. sound level meter (SLM) was positioned at a height of 1.2 m above the ground with a microphone grazing to the source and 7.5 m from the centre of the vehicle lane. Figure 3 shows the sound level (L_{Aeq}) against time history of multipurpose van (MPV) driven through MLO and its differences with the baseline (roadside sound level without TRS). The difference in noise levels was considered as it eliminated the effect of pavement surface, tyre tread and type, and axle weight. The peak noise levels were shown at the 6th second when the vehicle was directly in front of SLM at Point 1. The L_{Aeq} values produced was due to single vehicle that were driven through roadways with and without TRS were presented by using solid and dotted lines, respectively.





(b) Middle layer overlap (MO)



(c) Multiple layer overlap (MLO)

Figure 3. Layout and cross-section of TRS [19,20].

The investigation found that for Saga, Axia, and Alza, a maximum average increase of 6.5 dBA for the speed of 70 km/h, while for Hilux, Multipurpose van, a one tonne lorry and 40-seater school bus, the increase was not significant. The findings contradicted with the work done by An et al. [13] with milled TRS on concrete road surface that the increase in noise generated was greater for a truck (heavy vehicles) than a sedan (lightweight) at higher speed than lower speed. MLO also significantly absorbed SPL at 30 km/h with maximum SPL decrease of 4.9 dBA. For MO, the increase of SPL was only from vehicles GVW 2,000 kg with speed of 50 km/h but was not discernible (1.58 dBA). Overall, regardless of the type of TRS, the SPL increase was 2.58 dBA (≈ 3), which was perceptible by the human ear [19,20].

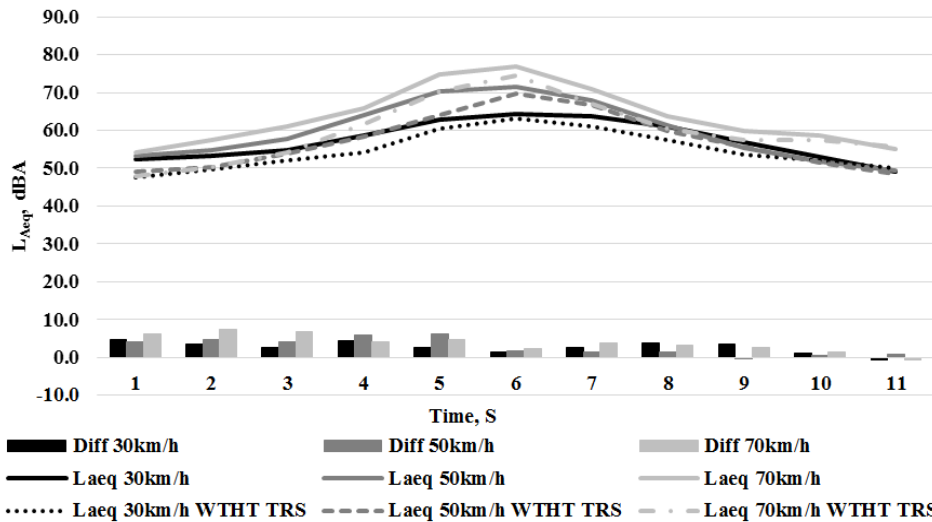


Figure 4. Noise level reading and changes with and without TRS when vehicle pass by the sound level meter [19].

The L_{AFmax} , L_{ASmax} , L_{AImax} , and L_{AIEqT} were used to determine the impulse characteristic. According to Ref 1, the impulse was significant when at least one of the different criteria shown in Equation 1 to Equation 4 was fulfilled.

$$L_{AImax} - L_{AFmax} > 2 \text{ dBA} \quad (1)$$

$$L_{AFmax} - L_{Aeq} \geq 10 \text{ dBA} \quad (2)$$

$$L_{AIEqT} - L_{Aeq} \geq 2 \text{ dBA} \quad (3)$$

$$L_{AImax} - L_{ASmax} > 6 \text{ dBA} \quad (4)$$

It was reported that Thermoplastic TRS yielded impulse of similar findings with the work by Sabato and Niezrecki [14] on 2 mm high bands of an elastoplastic. Impulsive sounds are characteristics of sound that have short duration with high amplitude, occurring at high rates of change, such as the knocking hammer sound [22].

METHODOLOGY

Previous study [19,20] was further extend on the changes and its impulsivity of sound produced by Saga, Axia, and Alza, Hilux, multipurpose van, a 1- tonne lorry, and 40- seater school bus. Instead of vehicle type, GVW was utilised, namely 850 kg (Axia), 1,075 kg (Saga), 1,140 kg (Alza), 2,780 kg (Hilux), 2,600 kg (MpV), 5,000 kg (Lorry), and 7,700 kg (Bus) to find the effect of GVW on the noise level changes and impulsivity of noise. The sound pressure levels when it measured at 7.5 m were extracted and combined to evaluate the relation between GVW and noise generation, with and without TRS and its differences.

Other variables include spacing, width, length, number of bar in each type of bar were also tested. In this paper, only data obtained for speed at 30 km/h and 50 km/h were analysed, as shown in Table 2. The SPL generation and changes in Table 2 for MLO and MO due to factors, such as GVM, spacing, width, length, and number of bar, were statistically tested. The noise generation and changes were tested by using Shapiro-walk for normality test for the significance of the sound pressure level changes. Then, regression analysis were utilized to determine the relation with R^2 value and significant probability (ρ) value of less than 0.05. According to previous research, R^2 of 0.25, 0.50, and 0.75 are weak, moderate, and substantial, respectively [23]. Correlation analysis was used to determine the strength of GVW as compared to others, such as spacing, width, length, and number of bar.

Table 2. Sound pressure level indices and impulsive criteria [19,20].

GVM, kg	Types of TRS	Speed, km/h	SPL with TRS	Increase or decrease	Impulsive criteria			
			L_{Aeq}	$(L_{Aeq} - L_{Aeqw})$	$(L_{AI_{max}} - L_{AF_{max}})$ Eqtn 1	$(L_{AF_{max}} - L_{Aeq})$ Eqtn 2	$(L_{AI_{eqT}} - L_{Aeq})$ Eqtn 3	$(L_{AI_{max}} - L_{AS_{max}})$ Eqtn 4
850	MLO	30	59.9	2.5	2.4	21.9	1.5	9.6
	MO		61	1.8	3.8	12.6	0.8	8.7
	MLO	50	66.7	2.5	1.7	16.8	1.9	5.8
	MO		68.1	0.9	1.3	17.9	1.0	3.4
1075	MLO	30	60.3	1.6	2.4	21.5	0.8	9.6
	MO		60.6	-0.5	3.9	14.1	0.8	9.6
	MLO	50	67.6	2.3	1.6	16.0	1.7	4.6
	MO		66.6	-0.5	1.3	19.4	0.9	3.4
1140	MLO	30	63.1	5.9	2.6	14.0	1.2	7.9
	MO		64.5	1.3	0.8	19.1	0.8	3.0
	MLO	50	70	6.5	3.6	7.7	1.5	11.6
	MO		71.5	1.7	1.7	7.1	1.1	4.0
2780	MLO	30	63.4	-0.4	1.4	17.6	0.8	2.9
	MO		65.8	-1.4	3.7	11.5	1	8.4
	MLO	50	69.1	-1.5	0.7	11.4	0.5	2.7
	MO		69.8	1.3	0.6	13.4	0.4	3.3
2600	MLO	30	60.9	-4.9	-1.5	15.6	1.2	0
	MO		63.3	-3.3	3.7	12.1	0.3	8.4
	MLO	50	69.2	2.4	0.7	15.2	0.4	2.7
	MO		68.8	1.2	1.4	15.9	0.8	4.9
5000	MLO	30	75.6	3	1.9	23.4	0.5	7.4
	MO		75.9	-0.5	2.1	5.4	0.8	7.1
	MLO	50	77.9	-2.5	0.9	8.1	0.8	3.3
	MO		81.4	1.7	0.8	7.8	0.8	3
7700	MLO	30	75.6	-1.6	1.8	14.1	0.7	7.3
	MO		78.5	2.9	2.6	7.4	0.7	8
	MLO	50	83.3	-2.5	0.9	2.7	0.2	3.5
	MO		85	2.2	0.8	4.7	0.3	3

Moreover, the extent of characteristic impulse was evaluated by using four criteria of indices difference stated in Equation 1 to Equation 4. If the value of any one of these criteria exceeded its reference value, it was assumed that the impulse was significant and showed

that annoyance or complaint may objectively attribute to TRS installation. Regression analysis was also used to determine of the effect of GVW. Finally, the impact of TRS on the environmental noise evaluation was suggested.

RESULTS

The relationship between GVW and noise level changes

Statistically, the distribution of noise level data with and without TRS follow the normal distribution when the test of Shapiro-Wilk showed $p > 0.05$ (Table 3). The effects of GVW on sound pressure level, with and without TRS, were firstly investigated, as shown in Figure 5. Generally, it was noticed that the sound pressure level was linearly increased as the GVW increased for both, with and without TRS. The trend in the increase was found to be in linear equation with very good relation for sound pressure level with TRS, where more than 70% of the variation in sound level were explained by the GVW. The associated p -value for the model was lower than 0.05, indicating that the model was considered to be statistically significant. Meanwhile, for sound pressure level, without TRS, a moderate relation was found where only 49% variation in sound level can be described by GVW. The trend suggested that sound pressure level with TRS was relatively lower for GVW below 5,000 kg. GVM 2780 represented by Hillux, which was a 4-wheel drive, demonstrated the least noise level changes may be due to the 4-wheel-steering (4WS) system that has an active steering system for comfort driving, as described by [24].

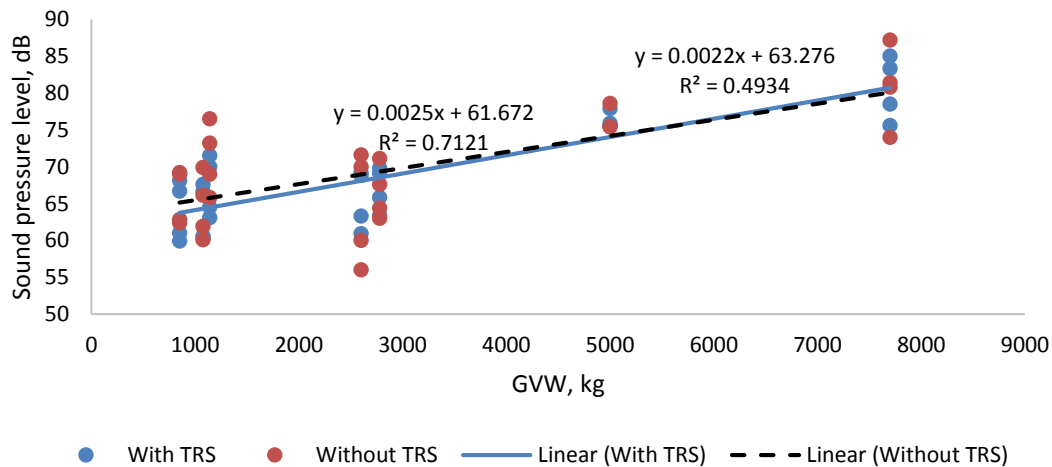


Figure 5: Relation between sound pressure level and vehicle weights

Consequently, the effect on noise level changes were carried out to eliminate the influence of factors, such as pavement surface or tyre thread. The data distribution of noise level changes also followed a normal distribution when the test of Shapiro-Wilk showed $p > 0.05$ (Table 3). It was then indicated that although TRS increased sound level by a maximum of 6.5 dBA by GVW 1,140 kg and reduced as much as 4.9 dBA by 2,600 kg GVW, overall, the mean sound pressure level change by less than 1 dBA. According to the T-test, the changes of sound pressure level did not significantly occur (Table 3) as $p > 0.05$.

Moreover, one T-test with a value of 3 dBA confirmed that the noise level changes was significantly away from discernible category ($p=0.000$).

Table 3. Descriptive analysis, Normality and T-test.

	Sound pressure level with TRS L_{Aeq} dBA	Sound pressure level without TRS L_{Aeqw} dBA	L_{Aeq} - L_{Aeqw} dBA	One t test L_{Aeq} - L_{Aeqw} Mean=3 dBA
Mean	69.41	70.19	0.78(≈ 1)	.78
Std. deviation	7.26	7.72	2.56	2.56
Minimum	59.90	56.00	-4.9	-4.9
Maximum	85.00	87.20	6.5	6.5
Normality test by Shapiro-Wilk				
Statistic	.93	.98	0.135	
df	28	28	28	
Sig.	.075	.88	0.43	
T-test				
t	-1.63			-4.56
df	27			27
Sig. (2-tailed)	.12			.00

In addition, the relation between GVW and the noise level changes can be shown by the correlation analysis shown in Table 4. The analysis showed that GVW has stronger correlation as compared to vehicle speeds for both with and without TRS. However, for the noise changes, both showed a weak correlation.

Table 4. Correlation analysis.

	SPL with TRS			SPL without TRS			SPL changes			
	SPL	GVW	speed	SPL	GVW	speed	SPL changes	GVW	speed	
SPL	1			SPL	1		SPL changes	1		
GVW	0.8	1		GVW	0.7	1	GVW	-0.2	1	
Speed	0.4	0	1	speed	0.4	0	speed	0.1	0	1

Table 5 shows the ANOVA result for regression analysis, indicating the effect of GVW on SPL noise generation when vehicles transited on TRS and its sound pressure level changed. It was found GVW, along with vehicle speed, were the significant variable for determining sound pressure level with TRS. Other variables included spacing, width, length, number of bar, and type were found insignificant as p -values were greater than 0.05. The

values of R^2 and adjusted R^2 were over 76%, which meant that the model provided a good explanation of the relation between GVW, speed, and the SPL generated by TRS. The obtained values of standard deviation and R^2 - predicted evidence that the proposed model was adequate to predict the SPL when the vehicle transited on TRS. A similar trend was observed on SPL generated without TRS.

The generation of SPL, with and without TRS, can be estimated by the following equation,

$$SPL(\text{with TRS}) = 49.2 + 0.003GVW + 0.32Speed \tag{5}$$

$$SPL(\text{without TRS}) = 49.54 + 0.002GVW + 0.34Speed \tag{6}$$

On the other hand, the increase of SPL generated by MO and MLO statistically did not pose a significant relation with any parameter investigated.

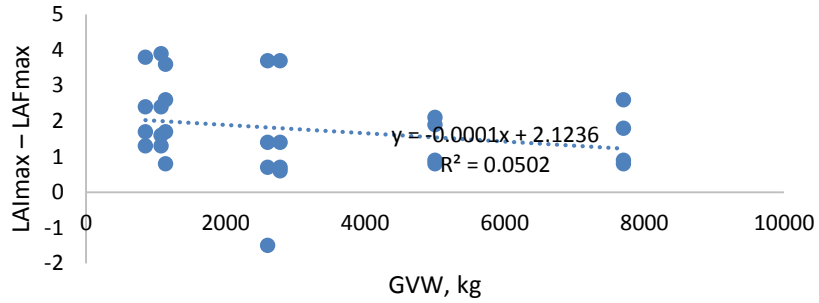
Table 5. ANOVA results for generated sound level, with and without TRS

Generation of SPL Due To TRS					
Source	Degree of freedom	Sum of squares	Mean squares	F-ratio	p-value
Regression	2	1273.56	636.78	106.23	0.00
Residual error	25	149.85	5.99		
Total	27	1423.41			
R² =89.47 %, Adjusted R²=88.63%					
Generation of SPL Due To road surface					
Source	Degree of freedom	Sum of squares	Mean squares	F-ratio	p-value
Regression	2	1135.16	567.58	29.98	0.00
Residual error	25	473.18	18.92		
Total	27	1608.34			
R² =84.01%; Adjusted R² =0.71					
Changes of SPL Due To TRS					
Source	Degree of freedom	Sum of squares	Mean squares	F-ratio	p-value
Regression	2	14.04	7.02	1.07	0.35
Residual error	25	163.65	6.54		
Total	27	177.70			
R² =28.1%, Adjusted R²=0.07					

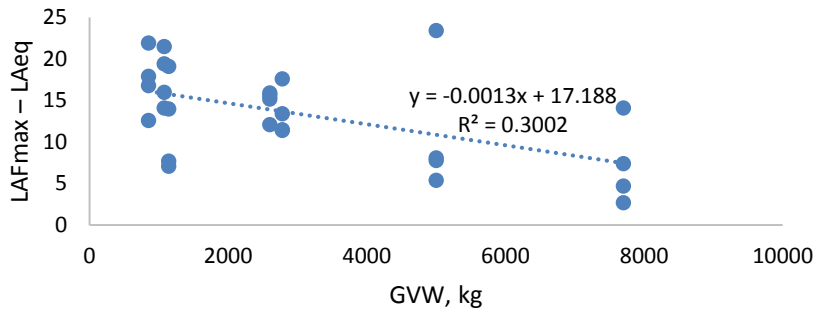
The relationship between GVW and noise level impulsivity

Figure 6 demonstrates the relationship between GVM and four differences of indices of $L_{AImax} - L_{AFmax}$, $L_{AFmax} - L_{Aeq}$, $L_{AeqT} - L_{Aeq}$, and $L_{AImax} - L_{ASmax}$. Generally, it was noticed that differences of indices linearly decreased as the GVW increased with R^2 values of 0.05, 0.30, 0.32, and 0.02 for $L_{AImax} - L_{AFmax}$, $L_{AFmax} - L_{Aeq}$, $L_{AeqT} - L_{Aeq}$, and $L_{AImax} - L_{ASmax}$, respectively. However, only $L_{AFmax} - L_{Aeq}$ and $L_{AeqT} - L_{Aeq}$ showed weak to moderate relation and the associated p -value for the model was lower than 0.05, which can be considered as statistically significant. The statistical description of sound for the impulsivity criteria is shown in Table

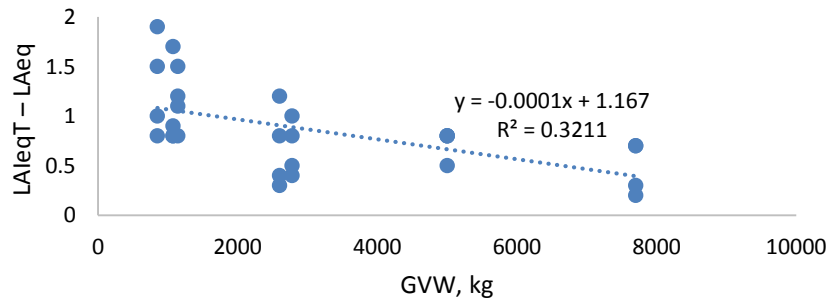
6. Consequently, it was noted that only $L_{AFmax} - L_{Aeq}$ exceeded the significant value of 10 dBA, revealing that TRS gave the significant impulsive characteristic when it was transited by vehicles with speeds of 30 km/h and 50 km/h.



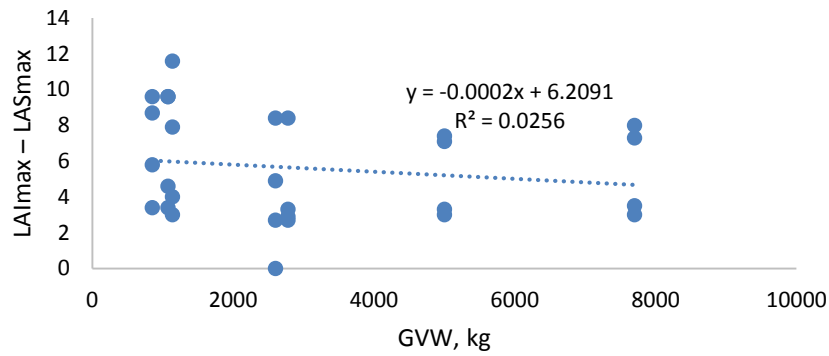
(i) $L_{AImax} - L_{AFmax}$



(ii) $L_{AFmax} - L_{Aeq}$



(iii) $L_{AeqT} - L_{Aeq}$



(iv) $L_{AImax} - L_{ASmax}$

Figure 6. Relation between impulsive criteria with the GVW.

Table 6. Descriptive analysis for impulsive criteria.

	L_{AImax} - L_{AFmax}	L_{AFmax} - L_{Aeq}	L_{AImax} - L_{Aeq}	L_{AImax} - L_{ASmax}
Mean impulse level	1.77	13.37	0.89	5.61
Median	1.65	14.05	0.8	4.75
Mode	0.8	14.1	0.8	9.6
Standard Deviation	1.24	5.48	0.41	2.94
Minimum	-1.5	2.7	0.2	0
Maximum	3.9	23.4	1.9	11.6
Comparison with limit, is it impulsive?	No	Yes	No	No

In addition to that, investigations were carried out on sound pressure level changes and impulsive characteristics on individual MLO and MO with the results shown in Table 7. Out of four criteria, MLO only produced one criterion that exceeded the limit, while MLO was with two criteria. Although MLO produced higher maximum SPL changes, both MO and MLO produced impulsive characteristic.

Table 7. Descriptive analysis for impulsive criteria for MO and MLO.

MLO					
	L_{Aeq}^-	L_{AImax}^-	L_{AFmax}^-	L_{AeqT}^-	L_{AImax}^-
	L_{Aeqw}	L_{AFmax}	L_{Aeq}	L_{Aeq}	L_{ASmax}
Mean	0.95	1.51	14.71	0.98	5.64
Standard Deviation	3.29	1.19	5.80	0.53	3.35
Minimum	-4.90	-1.50	2.70	0.20	0.00
Maximum	6.50	3.60	23.40	1.90	11.60
Comparison with limit, is it impulsive?		No	Yes	No	No
MO					
Mean	0.63	2.04	12.03	0.75	5.59
Standard Deviation	1.66	1.26	4.98	0.25	2.60
Minimum	-3.30	0.60	4.70	0.30	3.00
Maximum	2.90	3.90	19.40	1.10	9.60
Comparison with limit, is it impulsive?		Yes	Yes	No	No

DISCUSSION

The effect of GVW of vehicles on TRS noise can be seen through the direct relation between noise level generation and GVW, as the higher the GVW, the higher the noise generation. However, GVW did not pose a significant impact on the sound pressure level changes. The noise generation was slightly higher from that of without TRS when GVW was greater than 6,000 kg. In detail, it was determined not only there was a specific GVW that produced very high increase as considered highly perceived by the human ear (6dBA due to 140 kg GVW), there was also reduction to nearly 5 dBA (due to 2,600 kg GVM), but on average, the noise that changed over the selected range of GVW showed very low (1 dBA) or was not noticeable by the human ear. However, because of the impulse characteristic was shown by both TRS, this may be the reason of the complaints from the neighborhood as mentioned by Othman [9].

The increase in noise level was mostly due to lightweight vehicles, such as GVW less than 2,600 kg was mostly due to the speed of 50 km/h than 30 km/h. According to Sandberg [31], in normal road surface, generated noise from these types of vehicle are dominantly due to the tyre-road interaction, and in this case, tyre-thermoplastic interaction was higher. In this study, MLO dominated the higher increase, which was due to its profile that produce the tyres hit the contact surface with a higher angle of attack as compared to the normal road surface. This is called surface texture impact, which is dominant at 700Hz–1300Hz (Sandberg & Ejsmont, 2002). The increase of such sound level was reflected to environment since thermoplastic yellow bars possess properties of poor air permeability and high elasticity. Haron et al. [14] earlier proposed this mechanism when a compact car of 980kg transited on 3- layer overlap thermoplastic, as can be seen in the frequency spectrum in Figure 7.

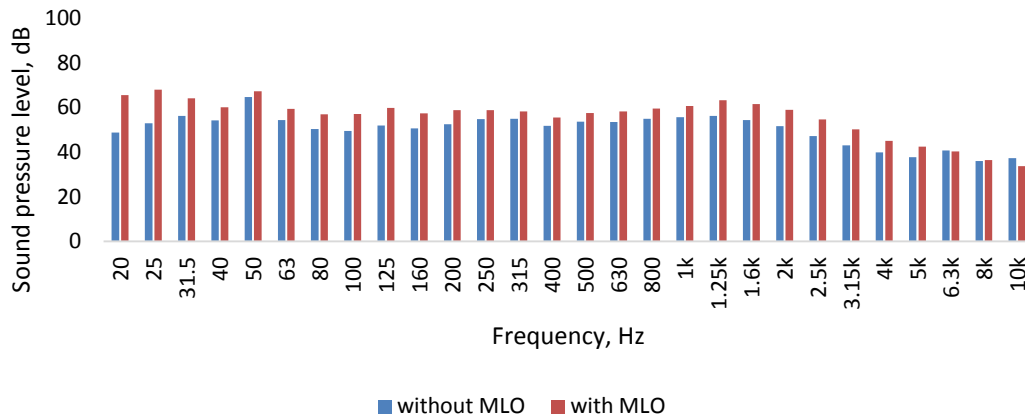


Figure 7. Frequency spectrum of sound pressure level changes of vehicle with GVM 980 kg transited on 3-layer overlap thermoplastic rumble strips at 50 km/h [14].

The reduction of SPL was dominated when the TRS were transited with 30 km/h and 50 km/h by low and high GVW, respectively. From the literature, such noise generation was dominated from power noise, with high noise level at low frequency region. In this case, it can be proven when the frequency spectrum of noise from medium weight vehicle 7,700 kg at a speed of 50 km/h was very high but in low frequency with maximum sound was at 125 Hz (89.6 dB) (Figure 8). This high sound pressure level then was absorbed by the thermoplastic surface of with the value drop to 83.7 dB and it is suggested that thermoplastic absorbed sound at the low frequency region and it was the nature of thermoplastic as discovered by Markiewicz (2012).

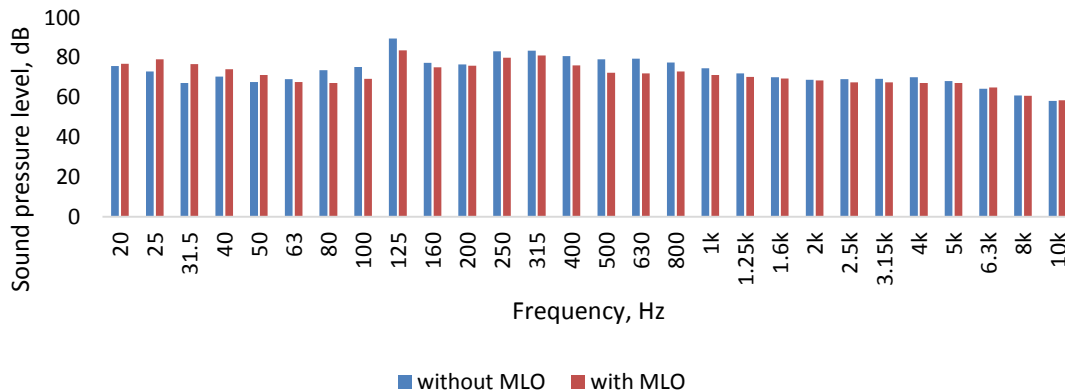


Figure 8. Frequency spectrum of sound pressure level changes of vehicle with GVM 7700 kg transited on MLO at 50 km/h [20].

Furthermore, the equation of generated noise in Equation 5 can be used to estimate the important sources of noise levels for roadside noise at speed between 30 km/h to 50 km/h. Apart from that, GVW affect the most of noise level changes as compared to the speed as can be seen from the probability value of the coefficient in Equation 5. Unlike noise level generation, impulse noise characteristic cannot be explained in linear equation. Despite that,

both TRS demonstrated impulsive characteristic. Therefore, this finding suggested that impulsivity should be considered when the environmental noise produced by the TRSs was evaluated. Based on the Malaysian legislation [35], correction factor of + 5 dB(A) should be added to the *L_{Aeq}* to account this impulsive noise.

CONCLUSION

This study investigated the effect of weight of vehicles, namely gross vehicle weight (GVW) when transited on TRS, with particular emphasis on noise level changes and impulsivity content. Data were obtained from a series of vehicles which weighed between 800 kg -8,000 kg based on previous research when these vehicles were tested at speed of 30 km/h and 50 km/h. It was found that the noise generated when the vehicles transited on TRS was strongly related with the weight of vehicles ($R^2=0.71$) higher than normal road surface ($R^2=0.49$). However, the changes of noise was not well represented by direct relation. It was found that TRS can increase and reduce sound pressure level, depending on GVW, but on average, TRS increased sound pressure level of 1 dBA. Despite that, TRS was found to have impulsive characteristic within the tested speed range. These findings can facilitate the authority when evaluating the environmental noise produced by the TRS.

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